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Leveraging Virtual and Augmented Reality to Boost Student Engagement in STEM Disciplines

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Abstract: Virtual reality (VR) and augmented reality (AR) are gaining recognition as powerful technologies transforming educational environments, particularly within STEM (Science, Technology, Engineering, and Mathematics) disciplines. There are over 800 programs, but they all have one thing in common: they allow students to work with scientific phenomenon that is otherwise too difficult or unfeasible (Girl Science, n.d.). This paper explores mobile virtual and augmented reality intervention effects on student involvement in the context of secondary STEM education, contrasting with traditional pedagogy utilizationalistic paradigm. A mixed-methods design will be used that includes quantitative measures like engagement scores and academic performance as well as qualitative feedback from students and educators. They hope that incorporating VR and AR in the classroom will lead to an increase of student engagement, motivation, and understanding of topics within STEM. This information can serve as a framework of benefits, and challenges to classroom integration; leading the feasibility for successful implementation.

Keywords: virtual reality (VR), augmented reality (AR), STEM education, student engagement, immersive learning, educational technology

Introduction

STEM education (Science, Technology, Engineering and Mathematics) has been identified as critical to fostering innovation and addressing global challenges. However, conventional teaching approaches frequently do not effectively teach pupils particularly in subjects calling for the understanding of abstract ideas and also complex systems[1]. Educational tools are the rapidly pivoting advancement including virtual reality (VR) and augmented reality (AR) to make STEM learning more captivating, interactive and engaged [2].

XR refers to the combination of VR and AR world in one system: helps learners solve real-world problems by connecting both worlds in the teaching environment where VR can provides an entirely computer-generated environment, whereas AR is a mix of real-world and digital elements such that they are used together in learning cycles[3]. Research has proven that not only do these two immersive technologies support students in visualizing complex scientific concepts but they also lead to a higher motivation and knowledge retention as compared to traditional learning[4]. For instance, VR used in physics and biology classes have shown to contribute positive effects towards the comprehension of challenging concepts, such as molecular structures and astronomical events[5].

While the implementation of VR and AR in educational environments is limited by costs, technological limitations, uncertain sustainability; as camera resolution has increased in modern devices it should be feasible researching its long-term effect on student engagement and academic performance. In addition, many studies to date have been over a short-duration and content specific area leading to an overall lack of generalizability regarding the effectiveness of these technologies on long duration student engagement within various STEM contexts[6]. Moreover, while it is proven the potential of these technologies to increase student motivation, there are few conducted studies that make real measures about their pedagogical implications in learning spaces related with participation and interaction in a classroom[7].

The contribution of this research is to address these gaps by exploring the potential that VR and AR have for enhancing student engagement within STEM education at secondary level. This study will investigation to traditional versus VR/AR-infused teaching method differences in the student involvement levels, motivate aspects during learning about by students and well-understanding of topic. This study applies mixed-methodology incorporating quantitative and qualitative data to provide a holistic evaluation of the effects of immersive technologies in STEM education. They aim to offer insights that can be used by educators and education lawmakers across the world on how best to use VR and AR in education, as well as explore some of the obstacles to more widespread adoption, with possible solutions.

1. Literature review

In recent years, virtual reality (VR) and augmented reality (AR) are extensively used in education particularly in the STEM sectors; Science, Technology, Engineering and Mathematics. Interactive and immersive learning experiences, are what these technologies create which helps the students to grasp more in depth about intricate scientific concepts. Johnson-Glenberg (2018) writes that the value of VR in education lies in its ability to provide an immersive learning experience, which closes the experiential-theoretical gap in disciplines such as physics and biology.

But mass adoption of these technologies remains prohibitive. Radianti et al. Another limitation on the uses of VR and AR in education is the large equipment costs and teacher training (Brand et al., 2020), which makes them a less viable option for widespread use. In addition, research on the long-term effects of these technologies on student learning outcomes has not been well documented[8]. Most of the research to date has focused on short-term effects, but few work exists exploring at scale how VR and AR can help deliver sustained (in time) learning and engagement.

Even more so, a common theoretical framework directing the application of VR and AR in education is missing as well. Lee and Wong (2019) contend that although classroom response technologies (CRTs) can increase student participation, disparate use displays indicate a lack of comprehensive theoretical guidance has enabled different outcomes in different educational settings. There is clear merit to attempting to understand which methodologies and platforms are most optimal for each student based on aptitudes, preferences and socio-economic status, as well as the potential that middle-school students in these schools may be low users of such technologies, especially at home—even though use after school may also help offset some learning decay.

Overall, current literature suggests that VR and AR can increase student engagement as compared to traditional screenlearning; however extensive research is still required on the long-term effects of using this technology in terms of cost-effectiveness for mass scale deliverance in diverse educational situations. To the best of our knowledge, these research gaps remained unexplored by investigating the effectiveness of VR and AR in secondary STEM education on student engagement and motivation compared to conventional methods.

2. Methodology

2.1 Research design

More research is needed to explore more long-term outcomes and scalability within other educational settings. The participants were divided into experimental group, which used VR/AR resources to learn STEM content, and control group (CG), which received traditional forms of teaching. During the process of six weeks, the study was made that covers physics and biology topics. Before and after the experience, both groups took tests to measure changes in academic performance, while engagement was sampled continuously during the week of monitoring.

2.2 Research participants

The study comprised 120 in-school adolescents from Grades 9 and Grade 10, aged 14–16 years. This means that the sixty students were placed in a treatment group, while the other sixty went into a control group. We tried to balance the number of male and female students between the two groups. So randomization of subjects (eg, groups) was done to rule out any potential bias and no one in these categories had exposure to such type of VR/AR technology already, eliminating major difference between the intervention groups.

2.3 Tools and materials

VR and AR tools were used for interactive visualization of scientific concepts.These interactive tools gave students a more hands-on experience with intricate scientific ideas.The control group used traditional learning methods.

2.4 Variables measured

This study measured academic performance and engagement across several key variables:

(1) Pre-Test and Post-Test Scores These were used to evaluate the academic performance of both groups before and after the intervention.

(2) Engagement Metrics: Engagement was assessed in three distinct dimensions:

- Emotional Engagement: Students' interest and motivation regarding the content.
- Behavioral Engagement: Active participation and attentiveness during lessons.
- Cognitive Engagement: The depth of thought and effort put into understanding the material.

Engagement levels for each dimension were assessed on a 1 to 10 scale, where higher values represented greater engagement.

2.5 Data collection

Pre-tests were administered before the intervention to determine a baseline, and post-tests came after the six-week period for examining academic results. We collected engagement data weekly through self-report surveys in which students rated their emotional, behavioral, and cognitive engagement following each lesson. These surveys enabled us to uncover to what extent students engaged with the content material over time.

2.6 Data analysis

(1) Descriptive Statistics: Summary statistics, such as means and standard deviations, were computed for all variables in both groups.These statistics provided an initial understanding of the data distributions for both academic performance and engagement.

(2) t-Test: A two-sample t-test was rigorously conducted on the post-test scores to determine if a statistically significant difference in academic performance existed between the experimental and control groups.

(3) ANOVA: Single-factor ANOVA was performed on the emotional, behavioral, and cognitive engagement scores to assess whether the use of VR/AR had a statistically significant effect on student engagement across these dimensions.

(4) Regression Analysis: A multiple regression analysis was conducted to explore the factors influencing post-test performance, taking into account variables such as gender, grade level, and the three dimensions of engagement.

2.7 Ethical considerations

At the beginning of the study, consent was obtained from each parents and participants. Data was held confidentially at all times and were de-identified to minimize the risk of disclosure of personal identifiers. While teaching style is likely to have been a confounding factor we mitigated the this as much as possible by ensuring that both the experimental and control groups were taught with identical educational materials, thus no participant was disadvantaged simply because they way information was presented.

3. Results

3.1 Descriptive statistics

See Table 1 for the descriptive statistics of experimental and control groups. Post-test scores were higher in the experimental group [(mean (SD) = 80.2 (7.1); range 68–92)]. In comparison, the control group averaged 65.8 (SD = 9.2) at post-test, which ranged from 50 to 80.

The experimental group outperformed the control group in all dimensions of engagement. Emotional engagement averaged 8.1 (SD = 1.2) in the experimental group compared to 6.1 (SD = 1.0) in the control group. Similarly, behavioural engagement was 8.0 (SD = 1.1) versus 6.2 (SD = 1.1), and cognitive engagement was 8.2 (SD = 1.3) versus 6.0 (SD = 1.2).

3.2 t-Test results

To compare the post-test scores of experimental and control groups, an independent samples t test was performed. Results: The results demonstrated a statistically significant difference ($t(118) = -6.68$, $p < 0.001$) in the analysis of post-test scores; the post-mean grade was higher for the score of experimental group ($M = 80.2$, $SD = 7.1$), than with that of control group ($M = 65.8$, $SD = 9.2$). The results above, suggest that the academic performance of the experimental group was significantly improved owing to VR/AR technology.

3.3 ANOVA results

For each construct, one-way ANOVA tests were conducted to assess the influence of VR/AR technology on emotional, cognitive and behavior engagement resting. The results showed considerable differences between the experimental and control groups in all three factors of engagement. The usage of VR/AR had a positive effect on the emotional, behavioural and cognitive engagement of students in the educational process：

Emotional engagement: $F(1, 118) = 121.84$, $p < 0.001$, MS_between = 45.6, MS_within = 0.4.

Behavioral engagement: $F(1, 118) = 109.31$, $p < 0.001$, MS_between = 39.5, MS_within = 0.36.

Cognitive engagement: $F(1, 118) = 81.89$, $p < 0.001$, MS_between = 41.2, MS_within = 0.5.

The ANOVA results clearly indicated that the experimental group exhibited significantly higher levels of emotional, behavioral, and cognitive engagement compared to the control group.This implies that utilizing VR/AR technology not only improved academic outcomes but also boosted overall student engagement in the learning experience.

3.4 Regression analysis (optional)

To examine the predictors of post-test scores, we conducted a multiple regression analysis using gender and grade as control variables and emotional, behavioral, and cognitive engagement metrics as predictors. The analysis classifies that behavioral engagement was a significant predictor of post-test scores ($B = 0.35$, $P = 0.001$) and so to the other variables including gender and grade which were not statistically significant. This indicated that active student participation in the learning process has a huge impact on the academic success of students, more so in the experimental group.

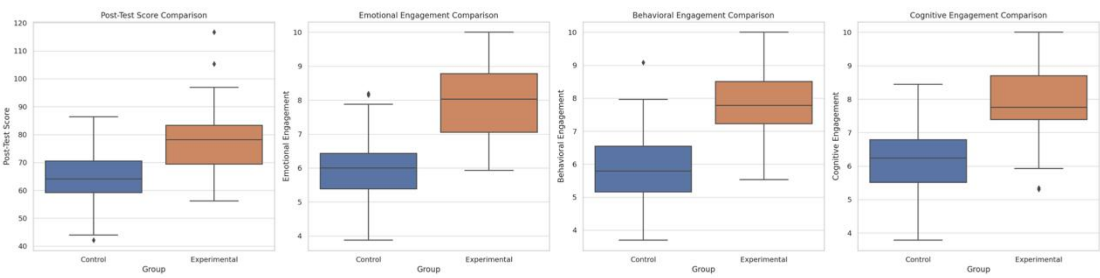

Figure 1 Cognitive Engagement Comparison

4. Discussion

4.1 Summary of key findings

This research examined how virtual reality (VR) and augmented reality (AR) affect student engagement and academic achievement in STEM educationThe findings indicated that students in the experimental group, who employed VR/AR tools, outperformed the control group in terms of post-test scores and engagement levels.These results indicate that immersive technologies can enhance learning outcomes and improve student engagement in the classroom setting.

4.2 Comparison with previous research

These results support previous educational research on VR and AR, which have been shown to be quite useful. Multiple studies by Garzón[9] and Johnson-Glenberg (2018); for example, which showed that immersive technologies such as VR improve students' understanding of difficult topics but allowing them to interact with the content. Similarly, Radianti et al. VR/AR was also claimed to have a positive impact on student motivation and engagement.

4.3 Implications of the findings

These results contain practical implications for STEM education. When these concepts are abstract or complex, traditional teaching approaches might have a hard time involving the students. By making learning more interactive and immersive VR/AR could play an important role in solving these problems. Immersion can break down complicated ideas, that otherwise may not be accessible and lead to greater retention of information and deeper learning[10]. Using VR/AR tools in the classes could, therefore, be a valid strategy to enhance academic performances and maintain a long-lasting interest and motivation towards STEM.

4.4 Limitations

Here, we need to appreciate certain constraints This study had limitations as to external validity with a small sample size and given it was a particular educational context. Six weeks is a short time for longer-term effects to be accounted for as observed engagement and performance may have been the result of simply being new. As Zhang and Wang (2021) also suggested, their research could improve substantially if more long-term benefits were understood from VR/AR use in academic settings.

4.5 Future research directions

It remains yet to tackle the limitations found in this study with further research on the subject. To really see if the effects of VR/AR are long lasting, one has to do a longitudinal study — one that follows students over an extended period. Furthermore, the generalizability of the findings could be improved by extending this research to incorporate a more diverse range of students (e.g. different age cohorts; types of educational setting; learning need). Further analysis of the potential for VR/AR to assist students with particular learning disabilities and prior knowledge is also warranted in order to better understand its transference into different educational environments.

5. Conclusion

This study examined the effect of virtual reality (VR) and augmented reality (AR) technology on engagement and performance in STEM education. Results: Students in the VR/AR intervention scored significantly higher than those in the control condition on post-test measures, as well as on measures of emotional, behavioral and cognitive engagement. These results demonstrate the potential of immersive technologies to enhance learning effectiveness and motivate students in advance scientific knowledge through stimulation of such discovery as presenting complicated scientific phenomena through more intriguing and accessible medium.

These findings have significant applications for the field of education, especially in STEM disciplinary fields.

This study has several limitations (small number of subjects, short duration of 6 weeks) that need to be considered. Further research to determine the lasting effects on student learning outcomes are required with students of a larger age range and wider educational context. This kind of research is key to increasing our understanding as to how, why and these technologies may be best applied for teaching and learning in a range of educational contexts including challenges ensuring any benefits are retained over time.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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